METHOD FOR MANUFACTURING A PERPENDICULAR WRITE HEAD

BACKGROUND OF THE INVENTION

1. Technical Field

[0001] The present invention relates in general to storage systems, and in particular disk drives. Still more particularly, the present invention relates to a method of fabricating a write head for use with perpendicular magnetic recording.

2. Description of the Related Art

[0002] A hard disk drive (HDD) is a digital data storage device that writes and reads data via magnetization changes of a magnetic storage disk along concentric tracks. As application programs and operating systems become longer with more lines of program code, and data files, particularly graphics files, become larger, the need for additional storage capacity on the HDD increases. Since the trend in HDD design is towards the use of smaller, rather than larger, disks, the solution to increasing the storage capacity of magnetic storage disks is to increase the areal density of data stored on the disk.

[0003] Currently, there are two main types of magnetic storage on a magnetic disk: longitudinal and perpendicular. **Figures 1a and b** depict these two types of storage. **Figure 1a** depicts the older technology of longitudinal recording. Longitudinal recorded bits **100** are stored when a longitudinal write head **102** magnetizes areas of a magnetic disk **104** in an orientation that is longitudinal to a track **118** on the magnetic disk **104**. As shown, the magnetic moment of each subsequent recorded bit is opposing, such that each north pole faces a south pole and vice versa. These opposing moments result in a repulsive force, which leads to long-term instability of the magnetized areas, thus leading to eventual lost data. Nonetheless, longitudinal recording has traditionally been the accepted method of storage because of the materials used to fabricate

magnetic disk **104** and the technological limitations on how small a pole tip of longitudinal write head **102** can be and still produce enough flux field to write data.

[0004] Modern disk fabrication materials have paved the way for perpendicular recording. These disk fabrication materials typically use a cobalt-chromium ferromagnetic thin film on an amorphous ferromagnetic thin film. This combination of materials affords both ultra-high recording performance along with high thermal stability. The concept of perpendicular recording is illustrated in **Figure 1b**. Perpendicular-recorded bits **106** are stored on a perpendicular recording medium **108** as anti-parallel magnets in relation to one another in an orientation that is normal (perpendicular) to the surface of the perpendicular recording medium **108**. Because the perpendicular-recorded bits **106** obey the pull of magnetic poles, they do not have the repulsive force of longitudinal recordings, and thus the perpendicular-recorded bits **106** are more stable.

[0005] While materials used to construct perpendicular recording medium **108** address part of the technological challenge of perpendicular recording, the other challenge is to fabricate a perpendicular write head **110** having a write pole tip **112** whose tip area is small enough to record the perpendicular-recorded bit **106** without overlapping an area reserved for another perpendicular-recorded bit **106**. This overlap must be avoided not only for bit areas on a same track **120**, but on bit areas on other tracks (not shown) as well. Thus, the aspect ratio (AR) of linear density (bits per inch – BPI) to track density (tracks per inch – TPI) should be controlled at 1:1 (BPI:TPI) or at most 2:1 to avoid adjacent track interference (ATI).

[0006] Furthermore, and more technically challenging, the perpendicular write head **110** must be able to produce a magnetic field that is powerful enough to magnetize an area for a perpendicular-recorded bit **106** without overwriting other bit areas or having to be so close to the surface of perpendicular recording medium **108** as to make head crashes likely.

[0007] As write pole tip **112** is scaled to tighter dimensions and constrained by the AR requirements described above, the amount of write field coming out at the tip of write pole tip **112** is attenuated and insufficient to magnetize the bit fields.

[0008] Two approaches that have been proposed to bring higher write flux to P3's write pole tip **112** are aggressive flare point and aggressive flux guide throat height in shaping layer **116** (P2). Experimental results have shown the tremendous difficulty in implementing aggressive flare point and P2 placement without encountering track-width variation and adjacent track interference (ATI). The ability to simultaneously control both flare point and track-width using ion milling approach is difficult due to the physical nature of this destructive method and the specification targeted. Equally challenging in bringing the flux guide layer closer to the Air Bearing Surface (ABS) are Adjacent Track Issues (ATI). (As is known to those skilled in the art of hard disk drives, as a disk spins under a read/write head, the small space between the read/write head and the disk is maintained by pressure of air passing between the read/write head and the disk surface, creating an "Air Bearing Surface," or ABS.) The P2 structure is much bigger in area at the ABS view as compared to the write pole. Effective write field, generated by an applied current, would prefer to leak from P2's surface closest to and facing the air bearing surface (ABS) instead of being funneled toward the pole tip. When P2 is brought closer to the ABS, it will bring more fields to the pole tip, but also adversely contribute significantly to ATI issues such as side writing and side erasure.

[0009] What is needed, therefore, is a perpendicular write head that has a very small write pole tip that is able to generate sufficient flux fields for magnetizing data bits areas without ATI issues, and a method to manufacture such a write head.

SUMMARY OF THE INVENTION

[0010] In view of the foregoing, the present invention provides a method for manufacturing a write head having a small write pole tip that emits magnetic flux sufficient for effective perpendicular recording. The method creates a leading edge taper (LET) between the write pole tip and a magnetic flux guide to create a sufficient magnetic flux in the write pole. The LET is fabricated by ion milling away a sacrificial striated material whose layers have different rates of ion milling. The top layer of material thus mills away faster than lower layers, creating the required tapering of a negative mold. An endpoint material stops the milling. The LET magnetic material is then spattered into the negative mold, resulting in a well defined taper of magnetic flux shaping material extending the magnetic flux guide to the write pole tip, such that the write pole tip is able to emit sufficient magnetic flux for perpendicular recording. The LET thus reduces P2 shaping layer's x-width to minimize adjacent tracking interference (ATI).

[0011] This method creates a write head that brings a more effective write field to the P3 pole tip and relaxes the stringent requirement to bring the flare point and P2 closer to the ABS to achieve higher effective write field. The effectiveness of tapering is best achieved when the tapering is self-aligned to P3 and the tapering angle is optimized at forty-five to fifty degrees.

[0012] The above, as well as additional objectives, features, and advantages of the present invention will become apparent in the following detailed written description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further purposes and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, where:

[0014] **Figure 1a** depicts a prior art longitudinal storage on a magnetic disk;

[0015] **Figure 1b** illustrates a prior art perpendicular storage on a magnetic disk;

[0016] **Figure 2** is a block diagram of a preferred embodiment of a data processing system using a hard disk drive (HDD) that incorporates an inventive write head;

[0017] **Figure 3a** depicts additional detail of the HDD that uses the inventive write head;

[0018] **Figure 3b** illustrates additional detail of hard disks in the HDD;

[0019] **Figure 4** depicts additional detail of a read/write head used in the HDD using the inventive write head;

[0020] **Figure 5** illustrates additional detail of the inventive write head in a preferred embodiment;

[0021] **Figure 6** depicts a side view of a preferred embodiment of the inventive write head;

[0022] **Figures 7A-G** illustrate inventive steps taken to fabricate a write head having a leading edge taper for guiding flux to a write pole;

[0023] Figures 8A-H illustrate inventive steps taken to fabricate a write head having a trailing edge taper for guiding flux to a write pole; and

[0024] Figure 9 depicts an inventive write head having both trailing and leading edge tapers.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0025] With reference now to **Figure 2**, there is depicted a block diagram of a preferred embodiment of a data processing system **200** using the present inventive write head in a disk drive. Data processing system **200** includes a processor **202**, which is connected to a system bus **208**. In the exemplary embodiment, data processing system **200** includes a graphics adapter **204**, also connected to system bus **208**, for receiving information for display **206**.

[0026] Also connected to system bus **208** are a system memory **210** and an input/output (I/O) bus bridge **212**. I/O bus bridge **212** couples an I/O bus **214** to system bus **208**, relaying and/or transforming data transactions from one bus to the other. Peripheral devices such as nonvolatile storage **216**, which may be a hard disk drive, floppy drive, a compact disk read-only memory (CD-ROM), a digital video disk (DVD) drive, or the like, and input device **218**, which may include a conventional mouse, a trackball, or the like, is connected to I/O bus **214**. Data processing system **200** connects with a network **230** via a network interface card (NIC) **226** as shown.

[0027] Network **230** may be the Internet, an enterprise confined intranet, an extranet, or any other network system known to those skilled in the art of computers.

[0028] The exemplary embodiment shown in **Figure 2** is provided solely for the purposes of explaining the invention and those skilled in the art will recognize that numerous variations are possible, both in form and function. For instance, data processing system **200** might also include a sound card and audio speakers, and numerous other optional components. All such variations are believed to be within the spirit and scope of the present invention.

[0029] With reference now to **Figure 3a**, there is depicted additional detail of a hard disk drive (HDD) **300** as contemplated by the present invention for use as nonvolatile storage **216** illustrated in **Figure 2**. HDD **300** has a set of hard disks **320**, which are rigid platters composed of a substrate and a magnetic medium. Since the substrate is non-magnetic, both sides of each

hard disk **320** can be coated with the magnetic medium so that data can be stored on both sides of each hard disk **320**.

[0030] An actuator arm **324** moves a slider **332**, which is gimbal mounted to the actuator arm **324**. The slider **332** carries a magnetic read/write head **322** to a specified lateral position above the surface of the hard disk **320** when a Voice Coil Motor (VCM) **326** swings the actuator arm **324**.

[0031] Data reads/writes between a data processing system **200** and magnetic read/write head **322** are under the control of a controller **304**. Controller **304** includes an interface (I/F) **312** coupled to data processing system **200**. Coupled to I/F **312** is a Hard Disk Controller (HDC) **308**, which coordinates read/write operations, and controls modes of operation of HDD **300**.

[0032] Coupled to a HDC **308** is a random access memory **306**, which caches data to be read/written on hard disk **320**. Read/write circuit **316** includes an Analog-to-Digital Converter (ADC) and a Digital-to-Analog Converter (DAC). The ADC is used to convert analog signals into digital signals for reads from the hard disk **320**. The DAC is used to convert digital values into appropriate analog signals for writes to the hard disk **320**. A MicroProcessor Unit (MPU) **310**, under the control of a micro-program stored in a Read Only Memory (ROM) **314**, controls a VCM driver **318**. VCM driver **318** controls movement of the VCM **326** using a 9-bit DAC, which converts a digital control signal from MPU **310** into an analog control signal for VCM **326**. Typically, VCM driver **318** also works in coordination with a controller (not shown) for spindle **328**, to provide proper positioning of read/write head **322** above the surface of hard disk **320** during read/write operations.

[0033] With reference now to **Figure 3b**, there is depicted additional detail of hard disks **320**. Hard disks **320** are a stack of hard disk platters, shown in exemplary form as hard disks **320a-b**. Preferably, more than two platters are used, but only two are shown for purposes of clarity. As a spindle motor **332** turns spindle **328**, each hard disk **320** connected to spindle **328** rotates at speeds in excess of 10,000 Revolutions Per Minute (RPMs). Each hard disk **320** has two surfaces, one or both of which can be magnetized to store data. Thus, hard disk **320a** is able to

store data on both sides using read/write heads **322a** and **322b**. Hard disk **320b** stores data on only one side using read/write head **322c**. Thus, the system illustrated in **Figure 3b** is a two-platter three-head HDD. By swinging the actuator arm **324** (and thus causing the movement of slider **332** and read/write head **322**) and rotating the spindle **328** (and thus spinning hard disk **320**), read/write head **322** can be positioned above any spot above the surface of hard disk **320**.

[0034] With reference now to **Figure 4**, there is depicted additional detail of magnetic read/write head **322**. Magnetic read/write head **322**, as the name implies, comprises both a read head and a write head, which are preferably separate components. While the read head is not depicted in **Figure 4**, a write head **402** is depicted. Write head **402** is mounted within slider **332**, and is aligned such that the write pole of write head **402** faces directly at the top surface of perpendicular recording medium **108**.

[0035] Referring to **Figure 5**, additional detail of write head **402** is given, showing a yoke **502** and a write pole tip **504**, which together are referred to as P3, positioned above a flux guide **506**, which is referred to as P2. Where write pole tip **504** meets yoke **502** is referenced as a flare point **508**. More about P3 will be discussed below.

[0036] **Figure 6** provides a side view of write head **402** (not to scale) as viewed from orientation 6-6 shown in **Figure 5**. Write head **402** includes write pole tip **504** next to air bearing surface (ABS) **118**. Write pole tip **504** joins yoke **502** at flare point **508** to form P3. Flux source **608**, typically coils, provides a flux field source to flux guide **506**, which shapes the flux field from flux source **608** to yoke **502** and write pole tip **504**. P1 **602** provides a return pathway for flux from write pole tip **504** to perpendicular recording medium **108** (not shown in **Figure 6**) and back to P1 **602** during write operations. A leading edge taper (LET) **604**, oriented between yoke **502** and flux guide **506** (P2) as shown, also shapes the flux field, between P2 and yoke **502** and write pole tip **504**. The purpose of LET **604** will be discussed below in greater detail.

[0037] Also shown in **Figure 6** is the preferred orientation of a read head **610**, which includes a read sensor **612**, to write head **402**. Read head **610** is capable of reading perpendicular recorded bits from a recording medium as described above.

[0038] **Figures 7A-G** and **Figures 8A-H** illustrate a series of steps taken in the present invention to fabricate the present inventive write head in its preferred embodiments.

[0039] For clarity, **Figures 7A-F and 8A-G** do not show flux source coils **608**. Beginning then with **Figure 7A**, a layer of sacrificial material **702** and a flux guide **506** are laid on top of P1 **602**, but separate from flux source **608** (not shown). Sacrificial material **702** and flux guide **506** are laid down using any method known to those skilled in the art of head fabrication, including various sputtering and other depositing techniques. Sacrificial material **702** is preferably aluminum oxide (AL_2O_3). P1 **602** and flux guide **506** (P2) are magnetic materials known to those skilled in the art.

[0040] In a preferred embodiment for fabricating flux guide **506**, a seed-layer is first laid down, followed by lithography to pattern flux guide **506**, and then plating flux guide **506**. The seed-layer is then removed with ion milling, and then sacrificial material **702** is deposited, followed by Chemical and Mechanical Polishing (CMP) to expose flux guide **506** (P2) and to define the thickness of P2.

[0041] As shown in **Figure 7B**, endpoint **704**, which is an ion detector/deflector, is then laid down. Endpoint **704** may be Ruthenium (Ru), Rhodium (Rh) or Copper (Cu), but is preferably Chromium (CR) or Nickel Chrome (NiCr). Endpoint **704** is preferably 20-30Å thick. The purpose of endpoint **704** is to stop ion milling, as discussed below, from milling into flux guide **506** (P2) and other sub-stratifications. In addition, endpoint **704** provides a completely fabricated write head **402** with a magnetostatically decoupler (separator) between P3 and LET **714**, shown below in **Figure 7G**. Endpoint **704** also induces in-plane anisotropy and magnetic softness in the LET **714** layer.

[0042] As shown in **Figure 7C**, a sacrificial leading edge taper (SLET) **706** is then deposited on endpoint **704**, and a resist **708** is laid at one end of SLET **706**. SLET **706** is made up of layers of non-magnetic materials, such as combination of the following materials: Al_2O_3, Ru, Cr, SiO_2, Ta, SiOxN, Si_3N_4, etc. Preferably, the top layer of SLET **706** is of a material that is opaque to minimize reflectively to achieve tight overlay and critical dimension control. The layers are

arranged to exploit the variation in the ion milling rates of these materials to create a steeper LET taper point (optimized at 45-50 degree). By controlling the thickness and placement of each film, the degree of tapering is thus well defined. Optionally, a CMP stop layer (not shown) is applied after the deposition of SLET **706**.

[0043] The layers have different milling rates, such that the higher layers mill away faster than the lower layers when hit by ion beams **710**. This unique property of SLET **706**, along with the guidance provided by resist **708**, and the ion milling conditions, results in the desired negative mold shown in **Figure 7D**, in which only a residual sacrificial LET shaper **712** remains after the ion milling. Note that endpoint **704** has stopped the ion milling from passing through to the P2 or P1 layers.

[0044] Next, magnetic material is laid into the space left by the milled SLET **706** to form LET **714**, as shown in **Figure 7E**. The magnetic material used to form LET **714** is preferably a high moment cobalt iron (CoFe), having 30-45% cobalt. Alternatively, LET **714** is made up of any CoFeX, where X is from a group of materials including nitrogen (N), boron (B) or nickel (Ni). The residual sacrificial LET shaper **712** is removed, leaving the structure shown in **Figure 7F**. In a preferred embodiment, the resist **708** is removed by depositing CoFe on the resist **708** and residual sacrificial LET shaper **712**, and then removing the newly deposited CoFe to remove both resist **708** and the residual sacrificial LET shaper **712**.

[0045] The yoke **502** and write pole tip **504**, together making up P3, are then laid down. In a preferred embodiment, P3 has alternating layers of magnetic and non-magnetic materials to inhibit remanence (writing after powering off due to stray fields).

[0046] Magnetic LET **714**'s x-direction is defined by ion milling. That is, ion milling is applied to P3 to define the shape of P3, and this ion milling is extended to define LET **714**. After both P3 and LET **714** are properly shaped with the ion milling, then the write head **402** having a magnetic LET **714**, as shown in **Figure 7G**, is complete.

[0047] The taper point of LET **714** has an angle between 40° and 50°, preferably 45°, as shown. This affords optimal shaping of flux between P2 and write pole P3, providing write pole P3 maximum flux strength for perpendicular writes in spite of the small cross section of write pole P3. Through the use of the specially chosen layers of non-magnetic materials used in SLET **706**, a precise 45° shape can be achieved as shown.

[0048] Note further that the optimal distance from ABS **118** to flare point **508** is the combined thickness of yoke **502** and LET **714**. These respective distances are shown on **Figure 7G** as "X" and "X'." This optimal distance reduces remanence by suppressing shape anisotropy.

[0049] Trailing Edge Taper (TET) materials are thus incorporated into the P3 fabrication. The write pole-TET layers consist of P3 materials, the endpoint layer, and the TET materials. During the P3 ion milling to fabricate the write pole, the TET's x-direction is also defined because it is part of the write pole. The encapsulation and CMP steps provide a planar surface to create TET's tapering. The tapering is achieved by a combination of guidance provided by resist and the ion mill conditions. Ion milling is terminated when the endpoint material is exposed during milling, leaving a tapered structure.

[0050] With reference now to **Figures 8A-H**, there are depicted steps taken in a preferred embodiment to fabricate a write head having a TET. The steps are similar to those taken in fabricating the write head with an LET, except that all milling of TET is positive milling, without a formation of an intermediate negative cavity as described in the formation of LET. That is, the milling of the TET directly leads the positive final shape of the TET. Striations consisting of magnetic and non-magnetic materials form the TET. The non-magnetic material is kept thin in order to minimize the flux carrying capacity of the TET.

[0051] Starting with **Figure 8A**, a high-resolution resist image **804** is laid atop a hard mask **802**. Hard mask **802** preferably has a top layer of a resist such as Duramide™ **816** (a resist that can be covered into an oxide for better ion mill resistance for fabricating the write pole) and a bottom carbon layer **814**. The hard mask **802** is atop a trailing edge taper (TET) **724**, which has striations of magnetic materials having different milling rates, analogous to SLET **706**. TET **724**

is laid atop a trailing endpoint layer **718**, which in a preferred embodiment is a non-magnetic material such as Ruthenium (Ru), having a preferable thickness of 8-10Å. Trailing endpoint layer **718**, like endpoint **704** discussed above, ultimately provides anti-ferromagnetic (AF) decoupling of a magnetic component of TET **724** and a P3 layer, as shown in **Figure 8H**. Trailing endpoint layer **718** is atop P3 and P2 as illustrated (coils **608** are not shown).

[0052] Referring now to **Figure 8B**, hard mask **802** is then partially etched away using Reactive Ion Etching (RIE), a chemical etching process, to begin the shaping of P3. As seen in **Figure 8C**, a second ion mill (physical ion milling process) is then used to mill away portions of the P3, trailing endpoint layer **718** and TET **724** to define a write pole with a pole bevel angle between 5 and 15 degrees, as illustrated.

[0053] As seen in **Figure 8D**, the structure is then encapsulated with an insulator **810**, preferably alumina (Al_2O_3). It is important to note that the height of insulator **810** should be slightly higher than hard mask **802** during CMP and encapsulation. This encapsulation provides three benefits. First, the alumina provides additional physical strength to the small and fragile P3 write tip. Second, the alumina protects the environment of the write area from the corrosive material that makes up the P3. Third, the alumina creates a planar surface to define the trailing edge of P3.

[0054] As seen in **Figure 8E**, a layer of carbon **812** is then deposited about insulator **810**. Note that carbon **812** should be at a height that is slightly higher than insulator **810** so that milling will stop at carbon **812** to define the trailing edge of P3 and TET **724**. The height of alumina **810** should be slightly higher than the hard mask **802** to provide write pole support during CMP. Deposition of DLC carbon on top of alumina **810** aids in the removal of hard mask **802** and redeposited materials during the P3 ion milling. Also, DLC carbon on top of alumina **810** reduces the CMP rate when hard mask **802** is removed to define the flatness of the trailing edge of P3.

[0055] Finally, as shown in **Figure 8F**, the carbon **812** and alumina **810** layers are polished away using a Chemical and Mechanical Polishing (CMP) technique, which stops at carbon layer **814** of hard mask **802**, while leaving Duramide layer **816** exposed.

[0056] Figure 8G is a side-view of **Figure 8F**. Magnetic TET **724**, comprised of striated layers of metallic material having different ion milling rates, is partially covered with a resist **820,** which afford the tapered edge of TET **724** through ion milling, leaving the final TET **724** shape shown in **Figure 8H**. Thus, TET **724** has striations of magnetic and non-magnetic materials that have different milling rates to promote the tapered shape shown with the non-magnetic material being thin enough to minimize the flux carrying capacity of the TET **724**. As with LET **714** discussed above, the taper point of TET **724** preferably is shaped at an angle between 40° and 50°, preferably 45°.

[0057] To illustrate a preferred orientation of write head **402** having a TET **724, Figure 8H** also depicts a read head **726**, which includes a read sensor **728**. Read head **726** is preferably a tri-layer construction oriented adjacent P1 **602** as illustrated.

[0058] In an alternative embodiment, the techniques described above to form TET **724** and LET **714** can be combined to achieve a write head **402** having both TET **724** and LET **714**, to produce a write head **402** as shown in **Figure 9**. Preferably, the process for forming LET **714** is performed first as described above, followed by the fabrication of TET **724** as described above.

[0059] The present invention therefore affords a method of manufacturing a write head having edge tapers that optimize the strength of flux reaching P3 for perpendicular writes. Flux is generated by flux source **608**, and the flux then passes in a controlled manner from P3 to the perpendicular recoding medium **108** to P1 with the shaping provided by P3 and the edge taper(s), but without creating remanence or ATI issues that would be caused without the precision of the taper to the edge(s) that the present invention affords. Upon completion of fabrication, the endpoints used to control milling are thin enough such that the endpoints do not affect the operation of either P2 or the edge tapers. Further, the material used to fabricate the endpoints are preferably magnetically transparent.

[0060] While the invention has been particularly shown and described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the

invention. It is also noted that none of the figures depicting the present invention are to be viewed as being to scale, unless otherwise noted.